International Basic and Applied Research Journal

Research Article (Subject – Petroleum geology)

Reservoir Characterization and Prediction of Reservoir Performance Using 3-D Static Modelling: Awe Field, Niger Delta, Nigeria

Awe Toba[1] and Richmond Uwanemesor Ideozu[2]

[1,2]Department of Geology, University of Port Harcourt, Nigeria.

Received: 22 April 2017, Revised Received: 30 July 2017, Accepted: 01 August 2017

Abstract

3D modelling has been used to gain understanding of reservoir uniqueness in Awe field, Eastern Niger Delta. A qualitative and quantitative approach was adopted to characterize and model the hydrocarbon bearing sands in the study area. Deviation/survey data, 3D seismic volume, wireline logs for five wells and checkshot data were used for this study. Reservoir zone G and I were delineated and correlated across the 5 wells using reservoir modelling software. The deterministic model adopted distributed the rock properties (structural, petrophysical and facie data) into a 3D grid using Sequential Gaussian Simulation and Sequential Gaussian Indicator algorithm. From this study three major faults were identified across reservoirs G and I. Reservoirs G and I have average thickness of 661ft and 558ft, net-to-gross of 78% and 75%, porosity of 29% and 26%, water saturation of 50% and 43%, permeability of 262.5mD and 77.06mD respectively. Based on Rider's classification reservoir G has very good porosity and very good permeability while reservoir I has a very good porosity and a good permeability. The delineated reservoirs are oil bearing and have a STOIIP (Stock tank oil initially in place) of 156MMSTB and 127MMSTB respectively. These values are satisfactory for economic production of the reservoirs. The environments of deposition of the reservoirs based on log motifs are interpreted as distributary channel fill and shoreface. The results of the porosity and permeability of Awe Field are in range of those reported in the Niger Delta. The STOIIP for reservoir G is higher than I based on the higher shale intervals in reservoir I. Reservoir I is a Shoreface deposit. The Shoreface deposit contains high shale content that could act as baffles to flow as seen in the 3D models of the lithofacies, porosity and permeability.

Keywords: Deterministic model, Porosity, Permeability, Channel fill, Shoreface, Niger Delta.

Introduction

Once hydrocarbon has been discovered in a field, additional studies are carried out to evaluate the reservoir, to understand the reservoir heterogeneity, delineate the extent of the reservoir in three dimensions and estimate the volume of fluid in the reservoir and to know the best development model to

adopt for maximum reservoir fluid recovery. It is widely recognized that reservoir characteristics such as: structures, lithofacies heterogeneity, spatial variability of porosity and permeability control the reservoir performance, development strategies and the returns on investment in the reservoir (Ailin et al, 2012). Reservoir characterization is the process of describing various reservoir characteristics such as geologic, petrophysics, geochemical and engineering properties. It also involves, using all available data to provide reliable reservoir models for accurate reservoir production and performance prediction, in addition to providing economic and safe decision making to determining the viability of the reservoir (s) under study (Jong-Se Lim, 2005). To have a comprehensive understanding of the reservoir, it is important to adopt qualitative and quantitative approach which is one of the thrust of this research. The 3D reservoir model is a geological model of the reservoir's spatial representation of the reservoir properties capturing key heterogeneity of the reservoir. Models are not precise representation of the real world but merely a computer-aided design showing property distribution of the reservoir characteristics which, helps in the prediction of the reservoir's future outcome. Reservoir models also help to identify the best and safest drilling, completion and recovery option for a reservoir as well as the most economic, efficient, and effective field development plan for that reservoir.

To build a geologic reservoir model, the reservoir should be described/characterized using available data obtained from well -points such as well directional/survey, well logs, drill cuttings, core, pressure point, geochemical and paleontology; and these data, are logged against depth at the wellsite. Well logs are very important in reservoir characterization and a vital source of quantitative data on porosity, permeability and fluid saturation. It is also useful in correlation and constructing both structural and stratigraphic cross-sections. Well log shapes are good indicators of reservoir depositional environment whereas seismic data contribute to the geometric description of reservoir structure and stratigraphy by meaningful interpretation of the data (Selley, 1978). Seismic interpretation is useful for structural and stratigraphic analysis, however the primary objective is to prepare contour maps (Emujakporue et al., 2012).

To characterize and develop models of reservoir properties in the field, it is necessary to integrate seismic interpretation, petrophysical properties and their distribution to provide reservoir models for predicting reservoir volumetrics. The reservoirs in the Awe Field were subdivided based on stratigraphic features and depositional environment in this research.

The aim of this research is to characterize and carry out 3D static modelling of "AWE FIELD" Eastern Niger Delta Nigeria. With the following the objectives: Correlate the reservoir across the five wells, delineate the hydrocarbon bearing reservoir, map out major faults within the field, compute the petrophysical parameters such as porosity, permeability net-to-gross ratio and water saturation using the deterministic approach. In addition to, inferring the depositional environment from well-log motif and relate the quality of the reservoirs to its environment of deposition, creating a 3D static petrophysical and facies model and evaluate the reservoir hydrocarbon volume. The study area is located within the south-eastern part of the coastal

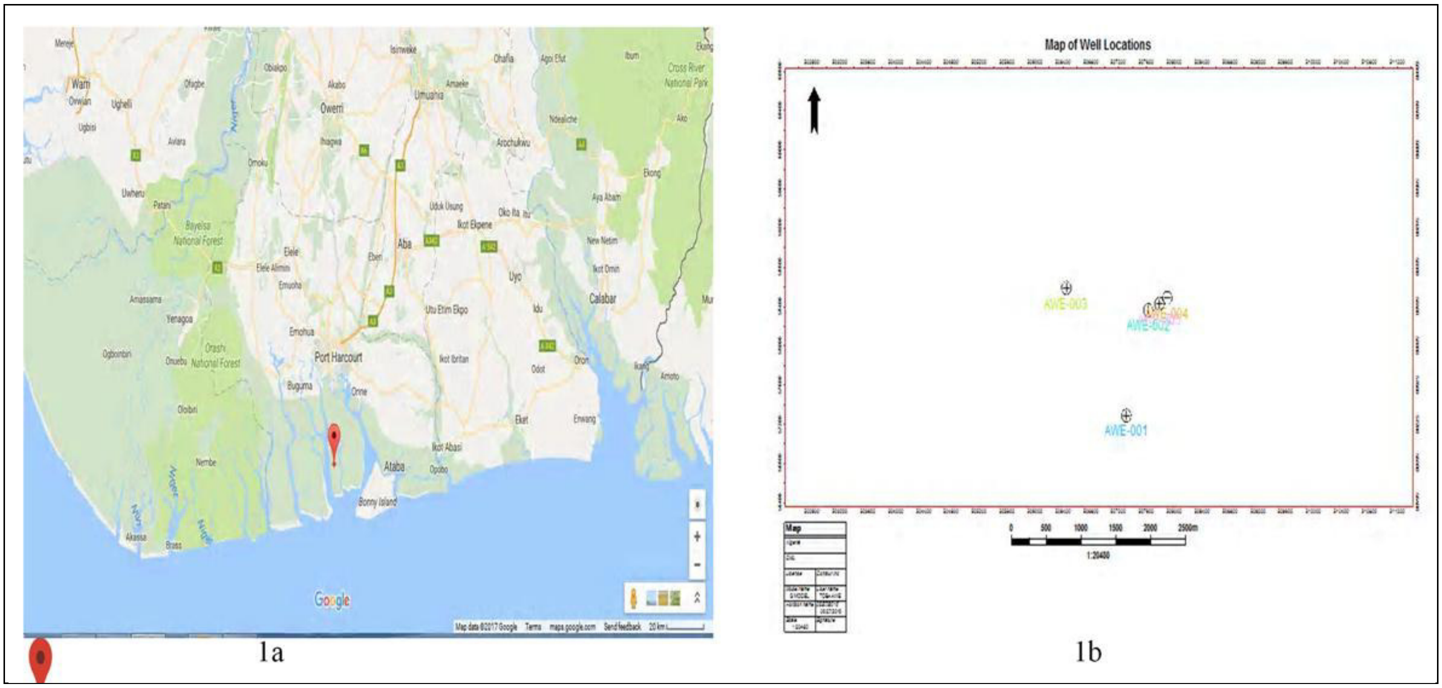
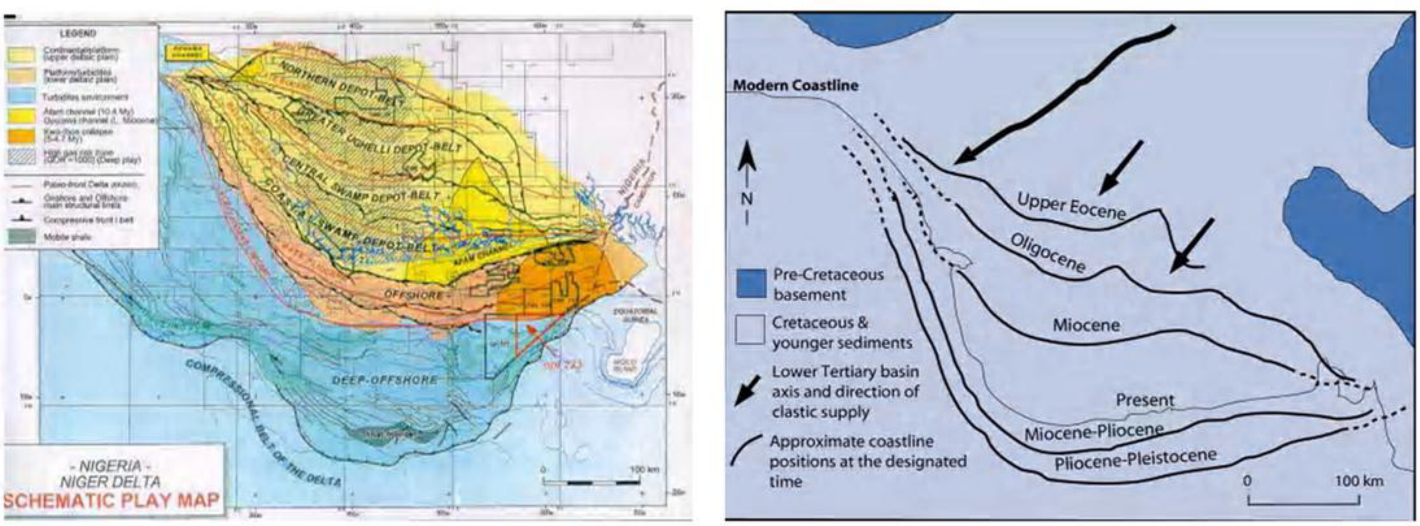


Figure 1. (1a) Map of southern Nigeria showing location point of study area and (1b) Base map of the study area with well-locations.



(2a) (2b)

Figure 2. (2a) Map of Niger Delta showing the depobelts and (2b) Cartoon showing how the coastline of Niger delta has prograded since 35 Ma (USGS, Niger Delta province).

swamp depo belt region of Niger Delta (Figure 1a & 1b; Figure 2a & 2b). The geology of the Niger Delta is well established, the stratigraphic and structural framework and petroleum geology (Doust and Omatsola, 1989, 1990; Reijers, 1996; Kulke, 1995; Ekweozor and Daukoru, 1994; Evamy et al, 1978).

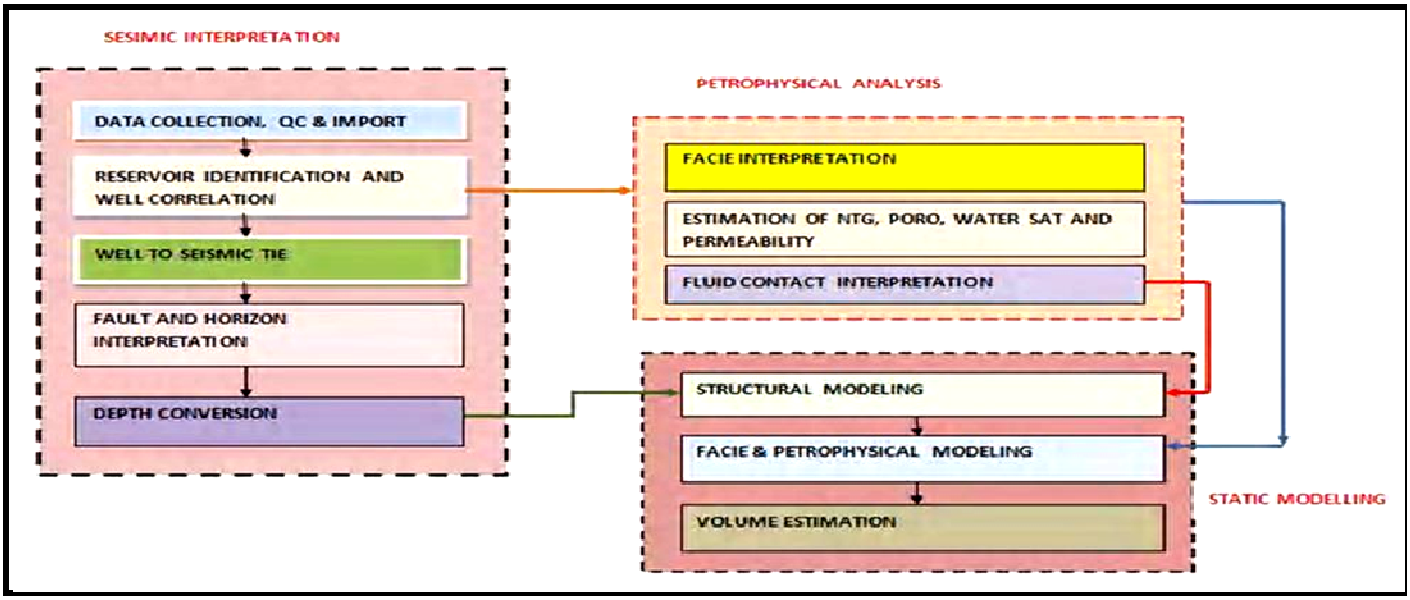


Figure 3. Methodological approach utilized in this study.

Materials and Methods

Materials

The data used for this research were obtained from an IOC in Nigeria for propriety reasons the source of the data may not be known and the data provided include 3D seismic data, well log data for 5 wells, deviation/survey data and checkshot data. Figure 3 is the work flow and methodology adopted.

Methods

The following quantitative petrophysical analysis and evaluation - Net-to-Gross (NTG), Porosity ($\square$), Water saturation ($S_{w)}$), and Permeability (K) from the well logs was carried out - The formula used to evaluate the petrophysical parameters are as follows:

Effective Porosity

$$\square_{eff} = \square_D - V_{sh} \times \square_{Dsh}) \quad (1)$$

Where:

$\square_{eff}$ Effective porosity

$\square_D$ = Total porosity

V_{sh} Shale volume

$\square_{Dsh}$ = Shale porosity from density log

Volume of Shale

$$Gr_{id} = (Gr_{og} - Gr_{in}) - Gr_{in}) / (Gr_{am} - Gr_{in}) \quad (2)$$

$$V_{sh=}0.083x(2^{(3.7xGRi)} - 1) \quad (3)$$

Where: GRi = Gamma ray index,
GR_{log} = Gamma ray log reading,
GR_{min} = Minimum Gamma ray log reading, which signifies clean sand and GR_{max} = Maximum Gamma ray log reading, which signifies 100% shale. Both equations calculate the volume of shale but equation 3 is the corrected one.

Permeability

$$K = (250 \times \square_{eff}{}^3 / S_{wirl)}{}^2 \quad (4)$$

Where:
K = Permeability
$\square_{eff}$ = Effective porosity
S_{wirr} = Irreducible Water Saturation [Tixer equation]

Water Saturation

S_w = 0.082 / □ (5)

Where:
S_w = Water saturation
□ = Effective porosity

Hydrocarbon types in the reservoir were correlated using resistivity and neutron/density logs to differentiate the fluid types and infer their contacts. The neutron log was used to delineate the oil-water contact - combined with the bulk density log. For reservoir sands, containing both oil and gas the neutron reading is higher in the oil zone compared to the gas zone. Neutron and density logs are usually placed in a single log track, such that both logs overlay in water bearing formation. In oil bearing sand, neutron porosity and density log overlay each other, showing minor positive separations and maintaining almost similar reading with the water bearing reservoir sand. Where there is gas in the reservoir sand, neutron porosity log deflects to the right, showing a decrease in neutron porosity while the bulk density log deflects to the left, giving a negative separation which is known as “balloon shape/structure.

Seismic Interpretation

Checkshot data for well 1, 3 and 4 were used to compute velocity required and seismic reflection coefficient which was used to create the synthetic seismogram. This is important in identifying the origin of the seismic reflection seen on the seismic section. The synthetic seismogram was tied to the seismic volume and used to pick the right event (reservoir tops). Faults typical of Niger Delta structure were mapped. Fault mapping on the seismic section was based on delineation of fault planes, reflection discontinuity at fault planes, vertical reflection displacement and abrupt termination and change in pattern of events across the fault (i.e. synthetic or antithetic faults). Horizons of the interested well tops where picked on the seismic using the time equivalent from of the reservoir well tops from Checkshot data. Two horizons where picked, horizon G and horizon I which, represent the tops of the delineated reservoir in “AWE” field

Seismic time and depth surface maps

Time maps for the two horizons of interest, horizon G and I, were created then converted to depth map using velocity model (Table 3). The velocity model converts the two-way time (TWT) map into the depth map with the equation: $V_0 + K^*Z$. Where V_0 is the Velocity of the mapped horizon, K is the constant at which the velocity changes and Z is the depth obtained.

3D Static Modelling

The 3D seismic data was used to generate horizon, polygon and grid data as framework for the 3D model. Deterministic model approach was adopted in the distribution of the rock properties (petrophysical and facie data) into a 3D grid using Sequential Gaussian Simulation and Sequential Indicator Simulation algorithm respectively. The result for the various petrophysical analysis such as net-to-gross (NTG), effective porosity (□), permeability (K) in mD, and water saturation (S_w) were used to used to estimate the volume of oil in the reservoir see equation 6.

STOIIP = (7758 x A X H x □ x NTG x $Sh_{y)}$ / Boi (6)

Where:

Boi = initial oil formation volume factor

A x H = Gross rock volume

The environment of deposition plays a key role in reservoir characterization as well as in reservoir

quality/performance prediction across the field. Reservoir sand bodies deposited in different depositional environments are characterized by different sand shape/geometry, size and heterogeneity. The depositional environment of reservoirs I and G was inferred from of well logs using standard shape of GR-log (Figure 4). Clastic sedimentary facies mostly display characteristic vertical profiles in which grain size fines upward, coarsens upward, or remains constant. Determination of such these vertical variations in grain size from GR-log is extremely valuable in the diagnosis of depositional environment.

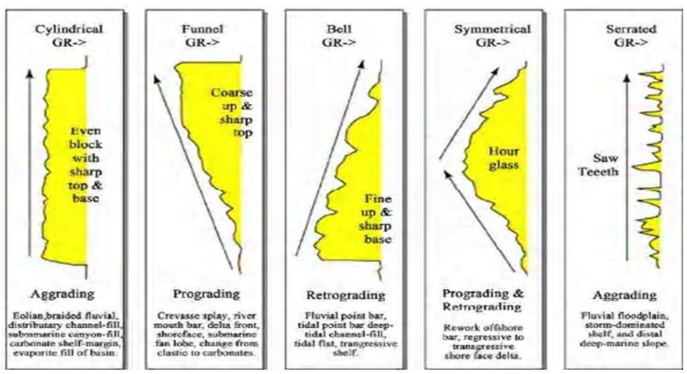


Figure 4. GR log response for different environment.

Results and Discussion

Results

The results of this research is presented are in Figures 5a to 15b and Tables 1 to 8. The correlation panel of the wells used in this study is displayed in Figure 5a and 5b. Information on the reservoir top and base depth (important data for geosteering and well placement) is displayed in Tables 1 and 2. Figure 6 shows the reservoir fluid type and contact with contact depth at 10950ft, 9750ft, 9750ft, 9750ft, and 9750ft for Awe 1, Awe 2, Awe 3, Awe 4 and Awe 5 respectively in SSTVD. Well-to-seismic tie that shows a good tie between the synthetic seismogram and the seismic inline, seismic fault and horizons mapping is displayed in Figures 7 and 8. Reservoir time map is presented in Figure 9a and 9b, and the depth structural map produced from the time map is presented in Figure 10a and 10b. Table 3 shows the velocity model used in converting the time map to depth structural map. Table 4 represents the petrophysical values obtained for both reservoirs 3D models of reservoirs structural, fluid contact, porosity, permeability and facies are shown in Figure 11a to 15b. The reservoirs volumetrics are summarized in Table 7.

Discussion and Interpretation

Petrophysics

Correlation gives the lateral extent and continuity of the reservoir across the five wells (Figure 5a and 5b). Three reservoirs (G, H, and I) where identified based on the resistivity log and hydrocarbon was identified in reservoirs G and I respectively. The reservoirs are predominantly sands with minor intercalations of shale and shaly sand, but with higher shale and shaly sand interbeds in reservoir I. The reservoir tops are penetrated at different depths in Awe 1, Awe2 Awe 3, Awe 4 and Awe 5 within structural and stratigraphic pattern of the Niger Delta (Tables 1 and 2). Average thickness of the shallow reservoir, G is 660.8ft (SSTVD), with an average net-to-gross of 0.78 (78%), porosity of 0.29 (29%), permeability of 262.5mD and water saturation of 0.5 (50%) (Table 4). Based on these values, the reservoir has a very good porosity and a very good permeability (Rider, 1986) see Tables 5 and 6. The reservoir shows no oil-water-contact but an oil-down-to (Figure 6). Reservoir I has an average net-to-gross of 0.75 (75%), porosity of 0.26 (26%), permeability of 77.1mD and water saturation of 0.43 (43%) (Table 4). The reservoir has a very good porosity and a good permeability based on Rider (1986) qualitative description of reservoir quality (Table 5 and 6). The reservoir shows oil-water-contact

Table 1. Reservoir G top, base and thickness

Reservoir G

Well Name	Top (Ft)	Base (Ft)	Thickness (Ft)
Awe 1	6714.12	7267.61	553.49
Awe 2	6497.9	7184.4	686.5
Awe 3	6507.09	7241.51	734.42
Awe 4	6424.18	7085.07	660.89
Awe 5	6454.97	7123.85	668.88
Average	6519.65	7180.49	660.84

Table 2. Reservoir I top, base and thickness

Reservoir I

Well Name	Top Ft	Base Ft	Thickness Ft
Awe 1	10588.51	11342.71	754.2
Awe 2	9362.11	9872.14	510.03
Awe 3	9456.07	9805.48	349.41
Awe 4	9290.8	9972.34	681.54
Awe 5	9334.93	9828.82	493.89
Average	9606.48	10164.29	557.81

Table 3. Velocity model

	A	B	C	D	E	F	G	H	I
1	**Velocity model**	Velocity model							
2	**User name**	TOBA							
3	**Project**	"AWE" FIELD PROJECT.pet							
4	**Date**	Friday, 22-07 2016 10:36:00							
5	**From:**	TWT [ms]							
6	**To:**	Z [ft]							
7	**XY:**	[m]							
8									
9	**Surface G**	**Well**	**X-value**	**Y-value**	**Z-value**	**Horizon after**	**Diff after**	**Corrected?**	**Information**
10		AWE-002	507625.4	58374.5	-6435.95	-6435.95	-0.00	Yes	
11		AWE-001	507309.1	57299.3	-6657.85	-6657.85	0.00	Yes	
12		AWE-005	507783.4	58440.3	-6402.03	-6402.03	0.00	Yes	
13		AWE-003	506447.6	58601.1	-6459.01	-6459.00	-0.00	Yes	
14		AWE-004	507896.2	58499.2	-6377.86	-6377.86	-0.00	Yes	
15									
16	**Surface I**	**Well**	**X-value**	**Y-value**	**Z-value**	**Horizon after**	**Diff after**	**Corrected?**	**Information**
17		AWE-002	507625.4	58374.5	-9313.65	-9313.65	-0.00	Yes	
18		AWE-001	507309.1	57299.3	-10535.14	-10535.14	-0.00	Yes	
19		AWE-005	507783.4	58440.3	-9280.91	-9280.91	0.00	Yes	
20		AWE-003	506447.6	58601.1	-9409.65	-9409.65	-0.00	Yes	
21		AWE-004	507896.2	58499.2	-9241.74	-9241.74	-0.00	Yes	

Table 4. Reservoir petrophysical values

	NET-TO-GROSS	POROSITY	WATER SATURATION	PERMEABILITY
SAND G	0.78	0.29	0.5	262.50
SAND I	0.75	0.26	0.43	77.06

Table 5. Qualitative description of porosity value (After Rider, 1986)

Porosity, (ɸ) in %,	**Quality Description**
0 – 5	Negligible
5 – 10	Poor
10 – 15	Fair
15 – 20	Good
> 20	Very good

Table 6. Qualitative description of permeability value (After Rider, 1986)

Permeability, K in mD	**Quality Description**
< 10.5	Poor
11 – 15	Fair
15 – 50	Moderate
50 – 250	Good
250 – 1000	Very Good
> 1000	Excellent

Table 7. Reservoirs volume estimation

	Reservoir Sand G	**Reservoir Sand I**
Bulk Volume (*10^6 ft^3)	27191	415823
Net Volume (*10^6 ft^3)	27191	239379
Pore Volume (*10^6 RB)	1405	7100
HCPV Oil (*10^6 RB)	422	355
STOIIP (*10^6 STB)	156	127

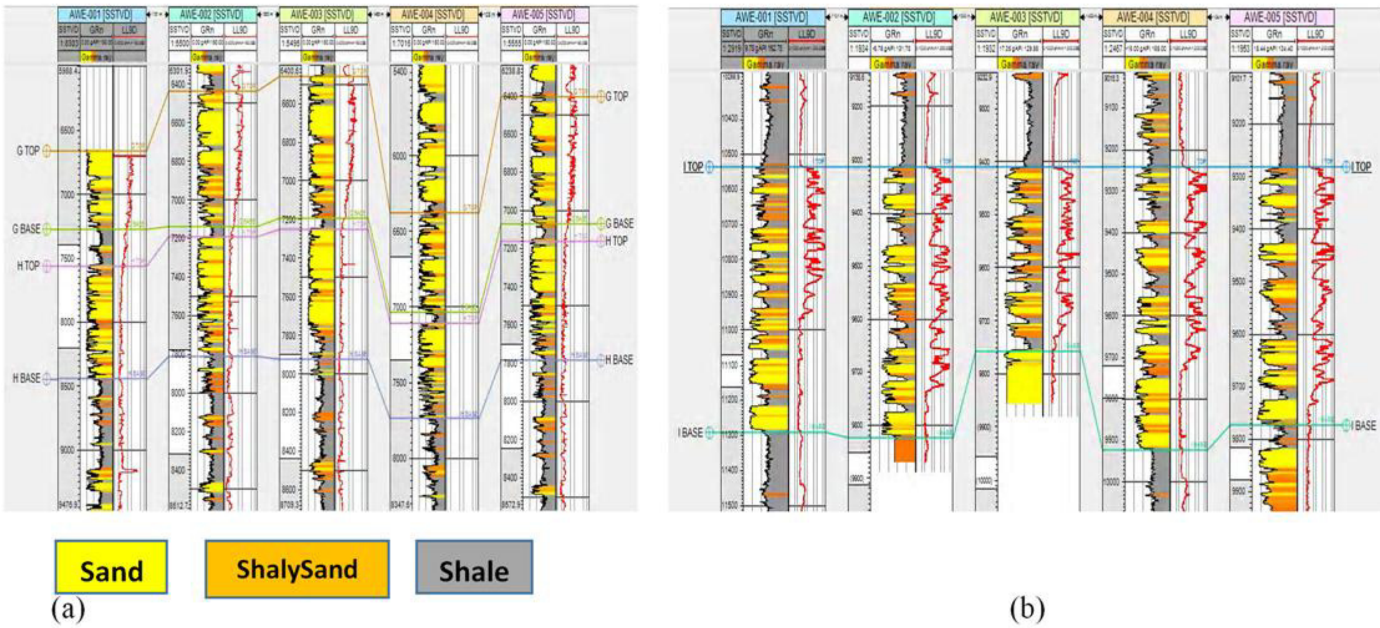


Figure 5. Well correlation panel.

at depth 10950ft (SSTVD) in Awe 1 and 9750ft (SSTVD) in the other wells (Figure 6). By comparing the two reservoir petrophysical values, reservoir G has the best hydrocarbon potential.

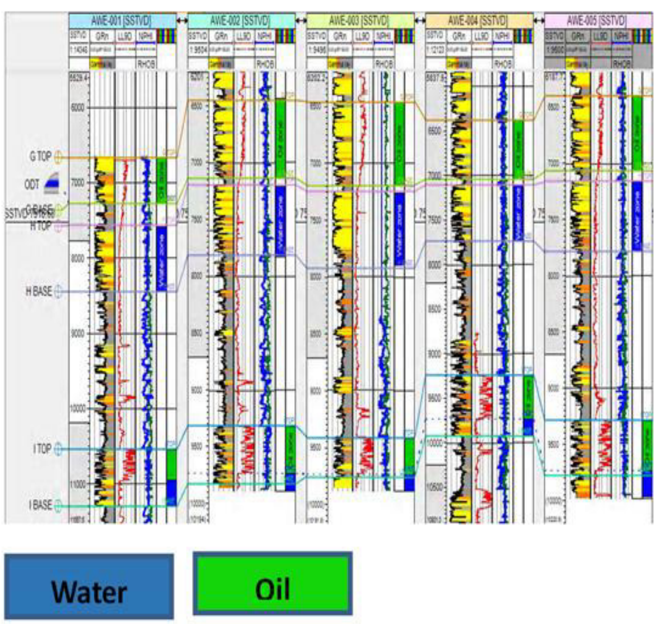


Figure 6. Hydrocarbon fluid contact.

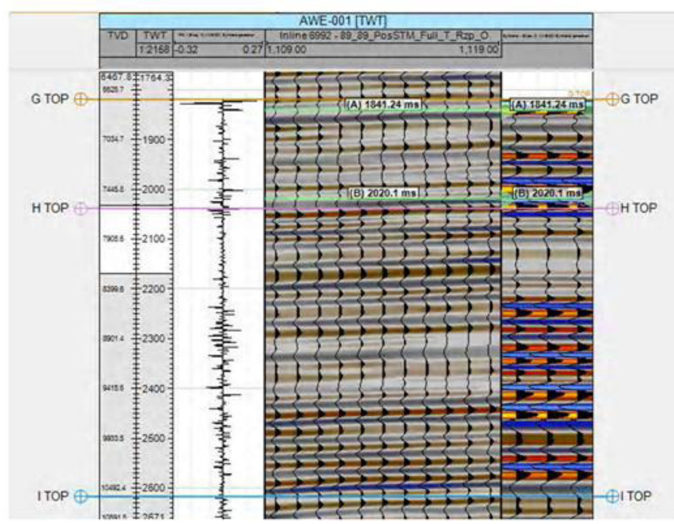


Figure 7. Well – to – seismic tie.

Seismic

Nine faults were delineated and typifies what is obtained in the Niger Delta - normal growth fault, rollover, collapse crest, and antithetic faults recognized by reflection discontinuity, displacement and abrupt termination and change in pattern of events (Figure 7). The rollover structure was observed

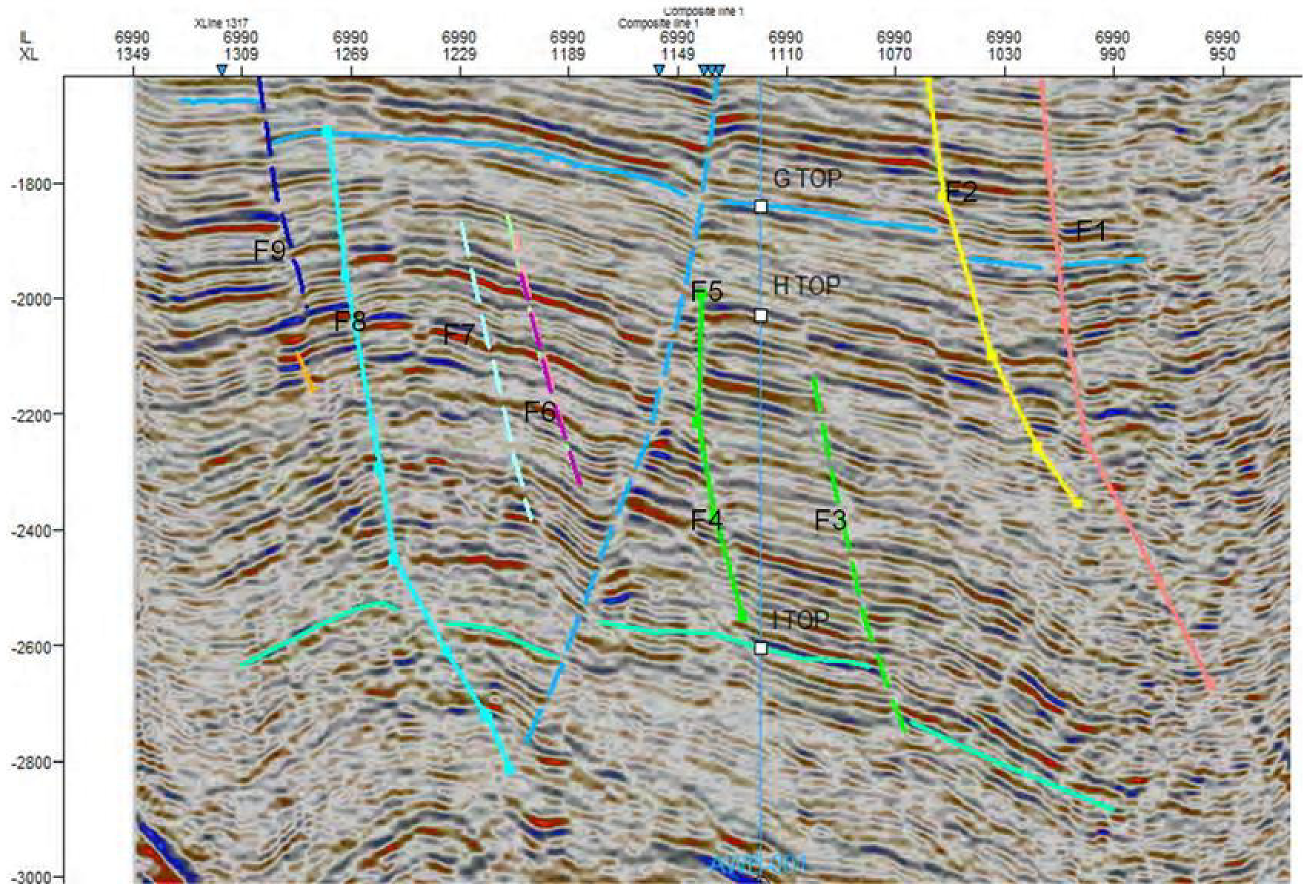


Figure 8. Fault and horizon mapping.

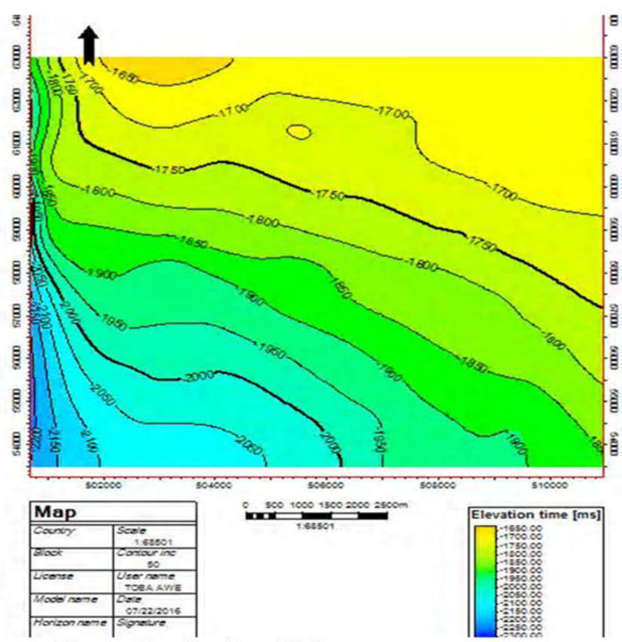


Figure 9a. Surface G time map.

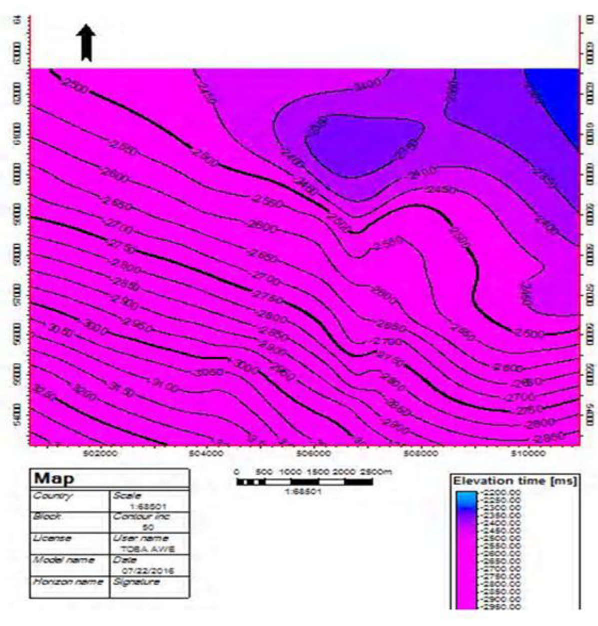
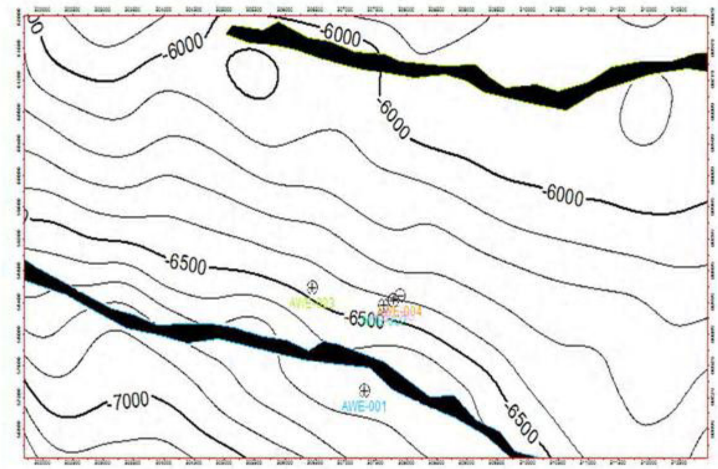


Figure 9b. Surface I time map.



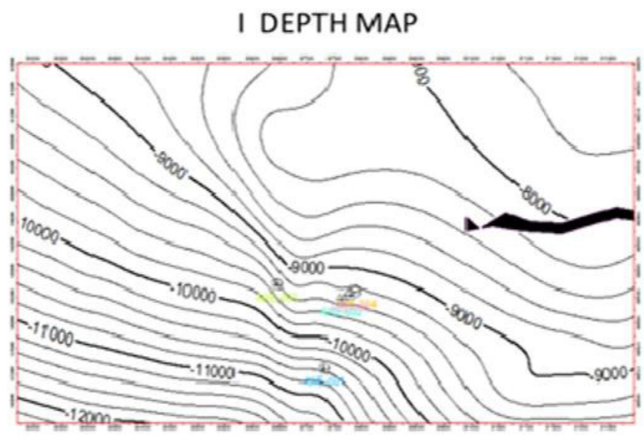
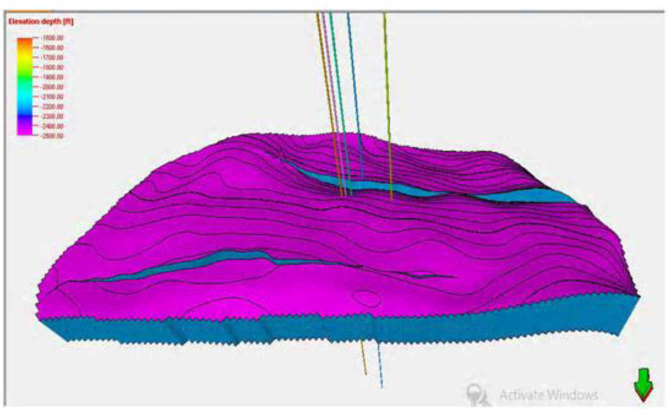


Figure 10a. Surface G depth structural map.

Figure 10b. Surface I depth structural map.



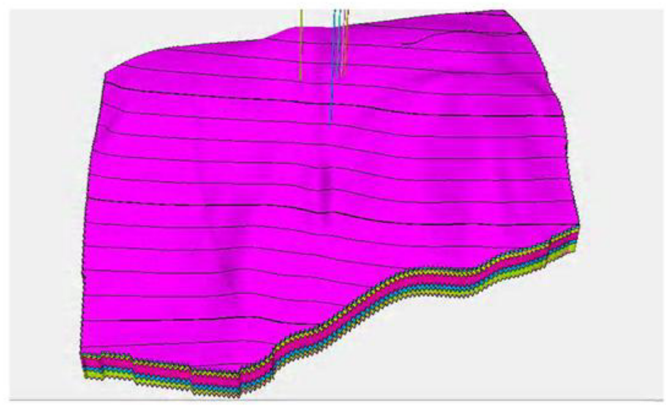
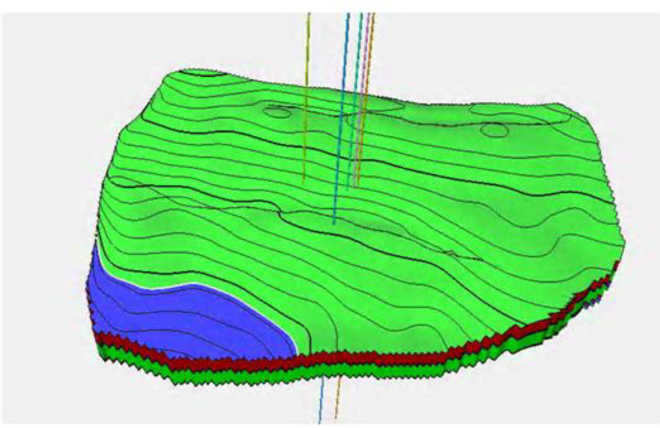


Figure 11a. Structural model of reservoir G.

Figure 11b. Structural model of reservoir I.



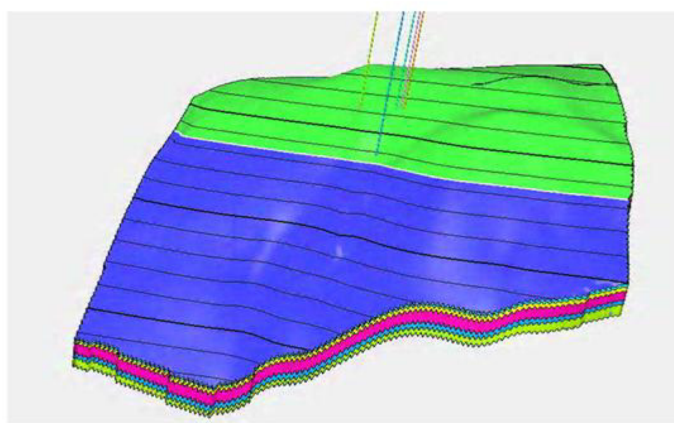


Figure 12a. 3D model of fluid contact for reservoir G.

Figure 12b. 3D model of fluid contact for reservoir I.

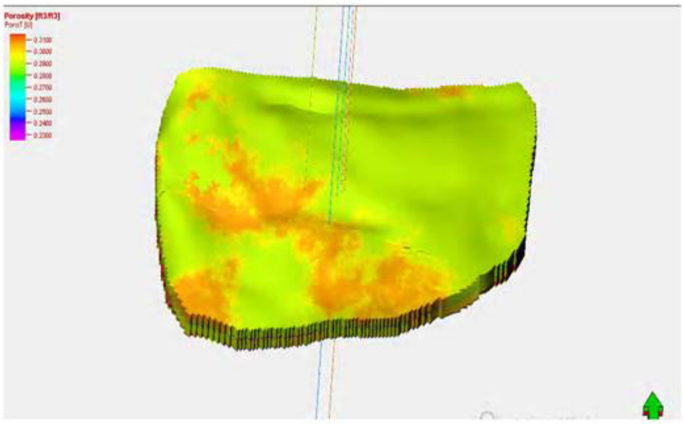


Figure 13a. Porosity model for reservoir G.

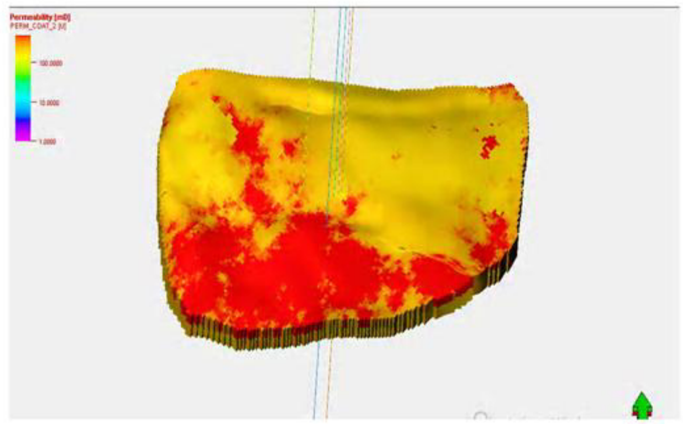


Figure 13b. Permeability model of reservoir G.

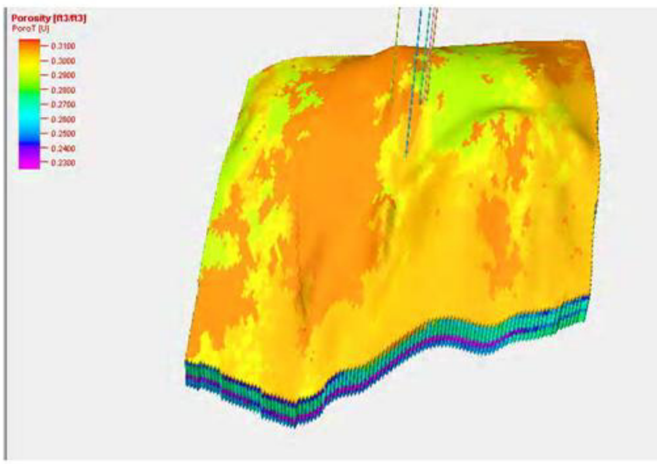


Figure 14a. Porosity model of reservoir I.

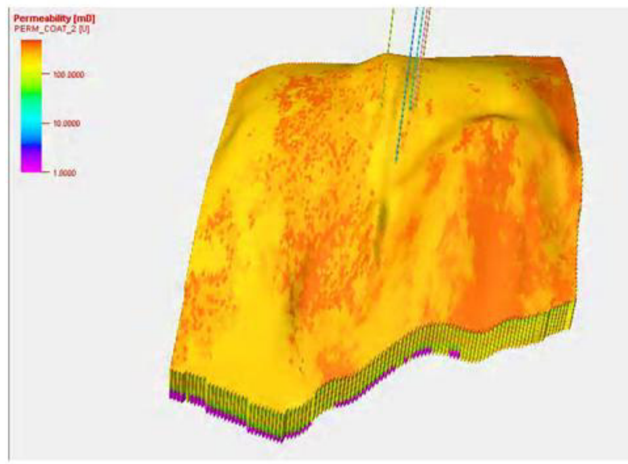


Figure 14b. Permeability model for reservoir I.

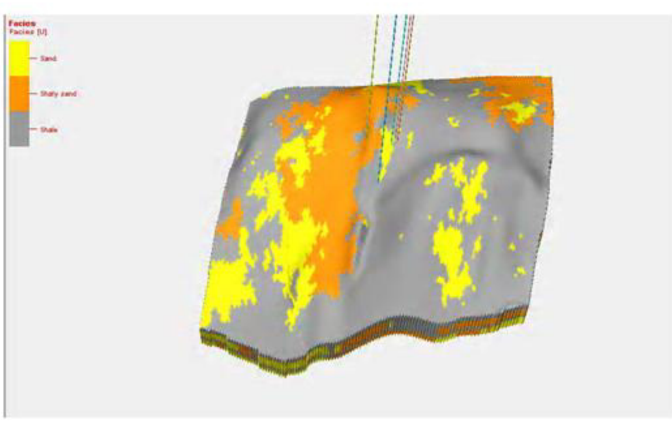


Figure 15a. Facies model for reservoir I.

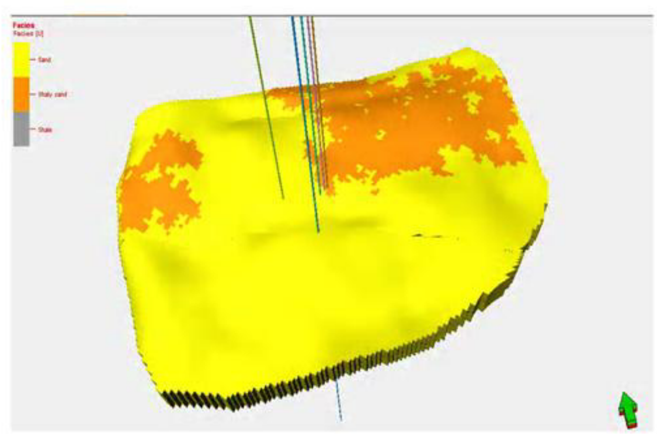
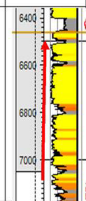
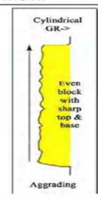
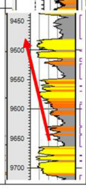


Figure 15b. Facies model for reservoir G.

Table 8. Environment of deposition interpretation.

RESERVOIR SAND	GR LOG SHAPE	DESCRIPTION	INFERRED DEPOSITIONAL ENVIRONMENT	STANDARD GR LOG MOTIF	INFERRED RESERVOIR QUALITY
G		Cylindrical pattern with minor shale intercalation	Distributary channel fill deposit		Fair to excellent depending on the size of the channel
I		Funnel shape, coarsing upward sequence	Shoreface deposit		Fair to Good

western section of the study area where all the wells were penetrated by both reservoirs while the southern is characterized with collapse crest (Figure 8). The seismic reveals structural complexity and both reservoir are faulted rollover anticline. From the structural map, reservoir G is bounded by two major faults and reservoir I shows more folding than the G counterpart due to the presence of shale (Figure 11a and 11b). These structural styles contribute to hydrocarbon accumulation and entrapment. The hydrocarbon is trapped in the faulted anticline. The synthetic fault and antithetic fault's trend in NW-SW and NE-SW direction respectively.

3d Modelling

The 3D structural model reveals the highs and lows present the area. Three wells (Awe 2, Awe 4 and Awe 5) are placed in the low angle anticline trough of the reservoir sand body G. The two reservoirs are purely oil-bearing (Figure 12a and 12b). The reservoir G does not have an oil-water-contact (OWC) but an oil-down-to (ODT) because the oil zone is separated from the water zone by shale interval. Reservoir I show oil-water-contact (OWC) and the model reveals that the reservoir contains more water compared to reservoir G (Figure 13a and 13b). G and I Porosity model reflects a range of 0.28-0.3 by colour variation (Figure 13a and 14a) and permeability model reveals the reservoir is above 250 mD for G and less than 100mD for I (Figure 13b and 14b). When compared with reservoir G, Reservoir I have low porosity distribution as a result of the influence lithofacies distribution has on it. Awe1 and Awe3 is located within the orange colour portion of the model; this correspond to the highest porosity level of the field. Highest permeability (red colour) is observed in G while low permeability is observed in I. Lithological model shows only two facies (sand and shaley sand) with sand predominately present in reservoir G while reservoir I shows three main lithofacies distribution (Figure 15a and 15b).

Volumetric Analysis

The Rock bulk volume ($10^6 ft^3$) for both reservoir G and I are 27191 and 475823 respectively. However, reservoir I with higher bulk volumes is less petroliferous due to higher shales content as seen in the petrophysical correlation panel (Figure 5a to 5b). The reservoirs G and I are oil bearing and the STOIIP (Stock tank oil initially in place) is estimated at 156MMSTB and 127MMSTB respectively using equation material balance equation in the software. These values look satisfactory for economic decision.

Depositional Environment

This litho-facies distribution influences the petrophysical values in the reservoirs. The environment of deposition from the gamma ray log when compared with standard logs motif (Figure 4; Table 8) has a cylindrical signature pattern for reservoir G and this signifies a distributary channel fill deposit. This inferred environment, is known to have minor shale intercalation and a fair to good porosity. The interbedded sand and shale in reservoir I represent an alternation of high and low energy level signifying a shoreface environment. The general

upward increase in bed thickness and sand indicates prograding Delta.

Conclusion

Hydrocarbon bearing reservoir rocks (G and I) has been delineated and evaluated for their reserves, fluid and contact and petrophysics. 3-D models of the reservoir structure, fluid contact, porosity and permeability, and lithofacies has shown that the delineated reservoirs have economic value. The reservoirs of interest, G - was penetrated at depths 6714.12 ft., 6497.9 ft, 6507.09 ft, 6424.18 ft, 6454.97 ft and I penetrated at 10588.51ft, 9362.11ft, 9456.07ft, 9290.8 ft, 9334.93ft across the wells. The intrinsic petrophysical analysis of the reservoirs (G and I) from the well logs show a NTG of 78% and 75%, porosity of 29% and 26%, water saturation of 50% and 43%, and a permeability of 262.5Md and 77.06Md respectively. These values suggest a reservoir with reserves considerably viable for economic production, having estimated stock tank oil initially in place (STOIIP) of 156MMSTB and MMSTB127 for reservoir G and I respectively. The 3D models show how the reservoir properties are deterministically distributed across the field. By comparing the petrophysical values of the reservoirs, reservoir G interpreted as a distributary channel it is believed to have a better hydrocarbon potential compared to reservoir I also interpreted as a Shoreface. The Shoreface deposit has high shale content that could act as baffles to flow. This high shale content has direct influence on the reserve volume estimation of the reservoir.

References

Ailin, J., Dongbo, H., & Chengye, J. (2012). Advances and Challenges of Reservoir Characterization: A Review of the Current State-of-the-Art, Earth Sciences. Imran Ahmad Dar (Ed.), *InTech,www.intechopen.com/books/earth-sciences/advances-and-challenges-ofreservoir-characterization-a-review-of-the-current-state-of-the-art.*

Amakwe, O.V. (2013). Using 3D Seismic Attributes and Geologic Modelling for Characterisation of Field “X” In Niger Delta. *Unpublished Thesis, Centre for Petroleum Geosciences, Institute of Petroleum Studies, University of Port Harcourt*.

Anthony A. A., & Aurelius O. O. (2013). Reservoir Characterisation and Structural Interpretation of Seismic Profile: A Case Study Of Z-Field, Niger Delta, Nigeria. *International Journal for Petroleum Processing, Petrochemistry and Coal Processing,.* 55(1), 37-43.

Archie, G. E. (1950). Introduction to Petrophysics of Geology of Niger Delta. *American Association of Petroleum Geologist Bulletin,* 761, 943-961.

Avbovbo, A. A. (1978). Tertiary lithostratigraphy of Niger Delta. *Bulletin of American Association of Petroleum Geology.* 62, 297– 306.

Burke, K. (1972). Long-Shore Drift, Submarine Canyons and Submarine Fans in Development of Niger Delta. *American Association of Petroleum Geologist,* 9 (1), 42-52.

Coates, G.R., & Dumanoir, J.L. (1974). A New Approach to Improved Log Derived Permeability. *The Log Analysis*, 15, 1, 17- 31.

Dewan, J. (1983). Essentials of Modern Open Log Interpretation., *Pen Well Publishing Company, Tulsa Oklahoma*, 361.

Doust, H., & Omatsola, E. (1990). Divergent/Passive Margin Basins. *American Association of Petroleum Geologists Memoir 48,* P. 239 -248

Diekuma T, Gu-Han M., & Liping W. (2014. Petrophysical Characteristics of Coastal Swamp

Depobelts Reservoir in the Niger Delta Using Well-Log Data. *Journal of Applied Geology and Geophysics,* 2(2), 76-85.

Dim C. I. (2013). Regional Stratigraphic and Structural Framework of Parts of The Eastern Coastal Swamp Depo-Belt of Niger Delta. *Unpublished thesis Department of Geology, University of Nigeria, Nsukka.*

Ebenebe U. O. (2007). 3-D Static Reservoir Modelling in D6200M and E5500M Reservoirs of Oxeye Field. *Unpublished Department of Geology, University of Port Harcourt, Port Harcourt*.

Ejedawe, J.E., & Okoh S.U. (1981). Prediction of Optimal Depth of Petroleum Occurrence in The Niger Delta Basin. *Oil and Gas Journal,* 79, 190-204.

Ekwesozor C. M., & Okoye N.V. (1980). Petroleum Source-Bed Evaluation of Tertiary Niger Delta. *America Association of Petroleum Geologist Bulletin,* 64(8), 1251-1259.

Etu-Efeotor, J.O. (1997). Fundamentals of Petroleum Geology, *Paragraphics, Jeson Services Publishers, Port Harcourt,* 146.

Garrett, M. Q., & Tammy, M W. (2014). Shoreface And Fluvial Reservoirs in The Lower Grand Rapids Formation, Taiga Project, Cold Lake *Oil Sands. Geoconvention Focus.*

Godwin, E, Nwankwo, C., & Nwosu, J, (2012). Integration of Well Logs and Seismic Data for Prospects Evaluation of An X Field, Onshore Niger Delta, Nigeria. *International Journal of Geosciences,* 3(4), 6

Ibex. A. C. (1980). The Agbada Shales as Major Source Rocks for The Niger Delta Petroleum: *Abstract of Proceedings, 16th Annual Conference, Nigerian Mining and Geosciences Society, Lagos, Nigeria.*

Obibi, E R. (2013). 3D Static Modelling and Petrophysical Reservoir Characterisation of Wabi Field in Onshore Niger Delta. *Unpublished M.Sc. Thesis, Centre for petroleum Geosciences, University of Port Harcourt.*

Jong-Se, Lim. (2005). Reservoir Properties Determination Using Fuzzy Logic and Neural Networks from Well Data in Offshore Korea. *Journal of Petroleum Science and Engineering,* 49(3), 182-192.

Kulke, H. (1995). Reginal Petroleum Geology of The World. Africa, America, Australia and Antartica. 2, 143-981.

Lambert-Aikhionbare, D.O., & Ibe, A.C. (1984). Petroleum Source-Bed Evaluation of Tertiary Niger Delta. *American Association of Petroleum Geologists Bulletin,* 68(3), 387-374.

Lukumon, A., Njoku, A., Olawale, O., Julius, F., & Musa B. (2014). Static Reservoir Modeling Using Well Log And 3-D Seismic Data in A KN Field, Offshore Niger Delta, Nigeria. *International Journal of Geosciences,* 4 (5), 93-106.

Michele, L.W., Ronald, R. C. & Michael, E.B. (1999). The Niger Delta Petroleum System: Niger Delta Province, Nigeria Cameroon, and Equatorial Guinea, Africa. *Central Region Energy Resources, U.S Geological Survey.* Open-File Report 99:50H.

Oghonyon, R., Njoku, A. F. and Itiowe, K. (2015). Seismic and Petrophysical Characterization of Selected Wells, Niger Delta. *International Journal of Science Inventions Today,* 4(1), 054-067.

Ogunole, V. F (2013). Reservoir Quality Evaluation Of “V” Field Offshore Niger Delta. *Unpublished,*

Centre For Petroleum Geosciences, Institute of Petroleum Studies, University of Port Harcourt.

Okiwelu, A.A., & Ude, I.A. (2012). 3D Modelling and Basement Tectonics of the Niger Delta Basin from Aeromagnetic Data, Tectonics - Recent Advances, Evgenii Sharkov (Ed.), *InTech, DOI: 10.5772/48158.https://www.intechopen.com/books/tectonics-recent-advances/3d-modelling-and-basement-tectonics-of-the-niger-delta-basin-from-aeromagnetic-data*

Oladipo, M K. (2011). Integrated Reservoir Characterization: A Case Study of An Onshore Reservoir in Niger Delta Basin, *Unpublished, African University of Science and Technology, Abuja.*

Olumuyiwa, O., & Matthew, N. (2012). Facies Interpretation from Well Logs: Applied to SMEKS Field, Offshore Western Niger Delta. *AAPG Search and Discovery Article 90155.*

Omokhodion, O.M., (2013). 3D Static Modeling and Reservoir Characterisation of “X” Field Offshore Niger Delta, *Unpublished, University of Port Harcourt.*

Opara, A.I, Anyiam, U.O., & Nduka, A.V, (2011). 3-D Seismic Interpretation and Structural Analysis of Ossu Oil Field, Northern Depobelt, Onshore Niger Delta, Nigeria. *Pacific Journal of Science and Technology,* 12(1), 502 -509

Otobo, E. (2005). Review of The Geology of Niger Delta, Nigeria. *African Journal of Science Enugu,* 3(1), 678-684.

Owolabi, O.O., Longjohn, T.F., & Aijenka, J.A. (1994). An Empirical Expression for Permeability in Unconsolidated Sands of The Eastern Niger Delta. *Journal of Petroleum Geology,* 17(1), 111-116.

Oyanyan, R.O., Soronnadi-Ononuwu, C. G., & Omoboriowo, A.O, (2012). Depositional Environments of Sam-Bis oil Field Reservoir Sands, Niger Delta, Nigeria. *Advances in Applied Science Research,* 3, 1624-1638.

Petrel Manual Version 3.3. *Technoguide, Aslakveien Oslo, Norway.*

Rebecca, B.L., & Paul, V. R. (1996). Integrated Seismic Reservoir Characterization and Modelling: A Gulf of Mexico 3D Case History. *Paper Submitted for GCSSEPM 1996 History*

Reijers, T.J.A. (2011). Stratigraphy and Sedimentology of The Niger Delta. Geologos. 17(3), 133-162

Reijers, T.J.A., Petters S.W, and Nwanjide C.J. (1997). The Niger Delta Basin, African Basins-Sedimentary Basins of The World. *Elsevier Science, Amsterdam,* 151-172.

Rider, M.H. (1986). The Geological Interpretation of Well Logs. *Caithness, Blackie, Glasgow, Scotand. (2nd Ed).* 151-165.

Rotimi, O. J. (2013). Reservoir Characterisation, Modelling and Lateral Predictions Using Multivariate Analysis: A Case Study of Hems Field, Bohaibay, Liaohe, China*, unpublished thesis*, *Department of Petroleum Engineering, Covenant University, Ota,* 197

Schlumberger, (1989). Principles and Application of Well Logs Interpretation, *Schlumberger Education Services, Houston, Texas.*

Tixer, M.P., ((1949). Evaluation of Permeability from Electrical Logs Resistivity Gradients, *Oil and Gas Journal,* 8, 75-90.

Weber, K. J., & Daukoru, E. (1975). Petroleum Geology of The Niger Delta: *9th World Petroleum Congress, Tokyo, Proceedings,* 2, 209-221.

Cite this article: Toba, A. and Ideozu, R.U. 2017. Reservoir characterization and prediction of reservoir performance using 3D static modelling: Awe field, Niger Delta, Nigeria. International Basic and Applied Research Journal, Volume 03, Number 08, pp. 1-17.